Assessment of the CODE MGEX Clock Products

E. Orliac, L. Prange, R. Dach, S. Schaer and A. Jäggi

Astronomical Institute of University of Bern (AIUB)
Bern, Switzerland

contact: etienne.orliac@aiub.unibe.ch

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Presentation Outline

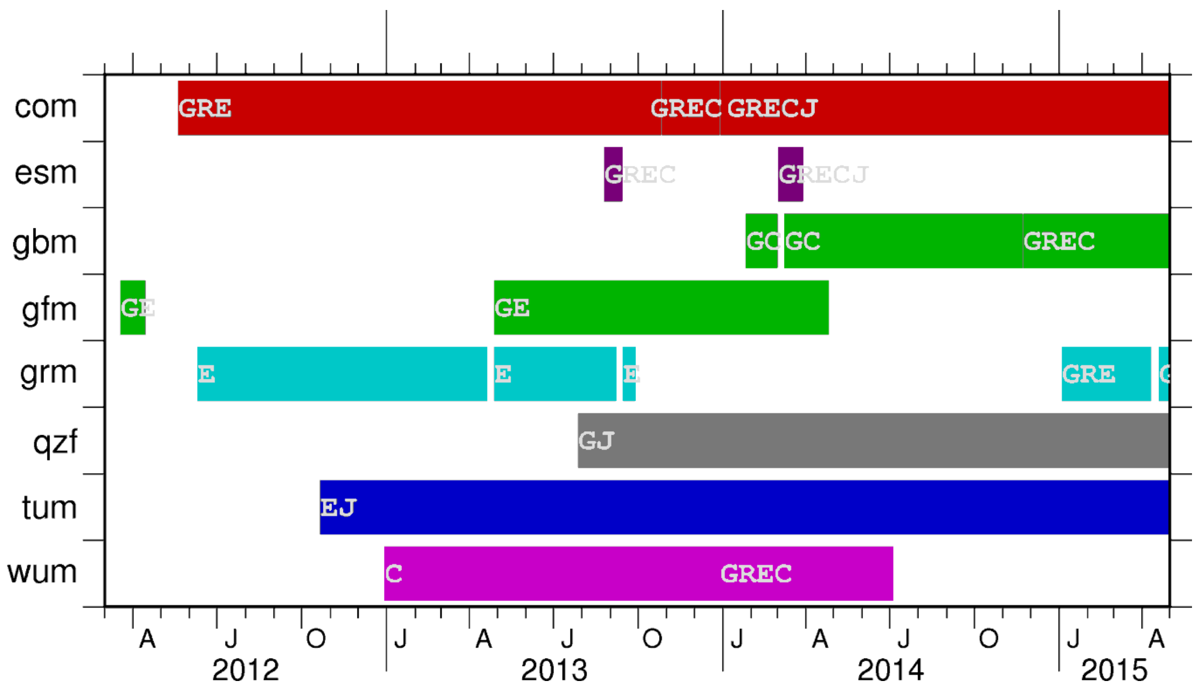
- Motivations
- Overview of the IGS MGEX
- Details on the CODE MGEX contribution
- New CODE SRP model (new ECOM)
- Assessment of the performance of satellites clocks
- Conclusions and outlook

Motivations

- Provide a consistent analysis of the satellite clocks perormances of the currently active five systems: GPS, GLONASS, Galileo, BeiDou and QZSS
- This study builds on [Prange et al., 2015]
- Evaluate the impact of the orbital arc length on the estimated clock parameters
- Evaluate the impact of the new CODE SRP model (new ECOM hereinafter) on estimated clock parameters

The IGS MGEX

- IGS: International GNSS Service
- MGEX: Multi-GNSS Experiment
- ‘*The Multi-GNSS Experiment (MGEX) has been set-up by the IGS to track, collate and analyse all available GNSS signals*’



CODE MGEX Contribution

- Operational rigourously combined processing of five systems:
  GPS (32), GLONASS (24), Galileo (7), BeiDou (8), QZSS (1)
  That is 72 satellites currently considered
- 2-week latency
- Stations: 130 (GPS), 110 (GLONASS), 85 (Galileo), 55 (BeiDou), 20 (QZSS)
- Orbit solution: double-difference with AR within each system
- Clock solution
- Processed signals:
  - GPS + GLO+ QZSS: L1+ L2
  - Gal: E1 (L1) + E5a (L5)
  - BeiDou: B1 (L1) + B2 (L7)
- Product availability: ftp://cddis.gsfc.nasa.gov/gnss/products/mgex/
- CODE MGEX products: comwwwwd.???.Z

SRP modelling: the old ECOM

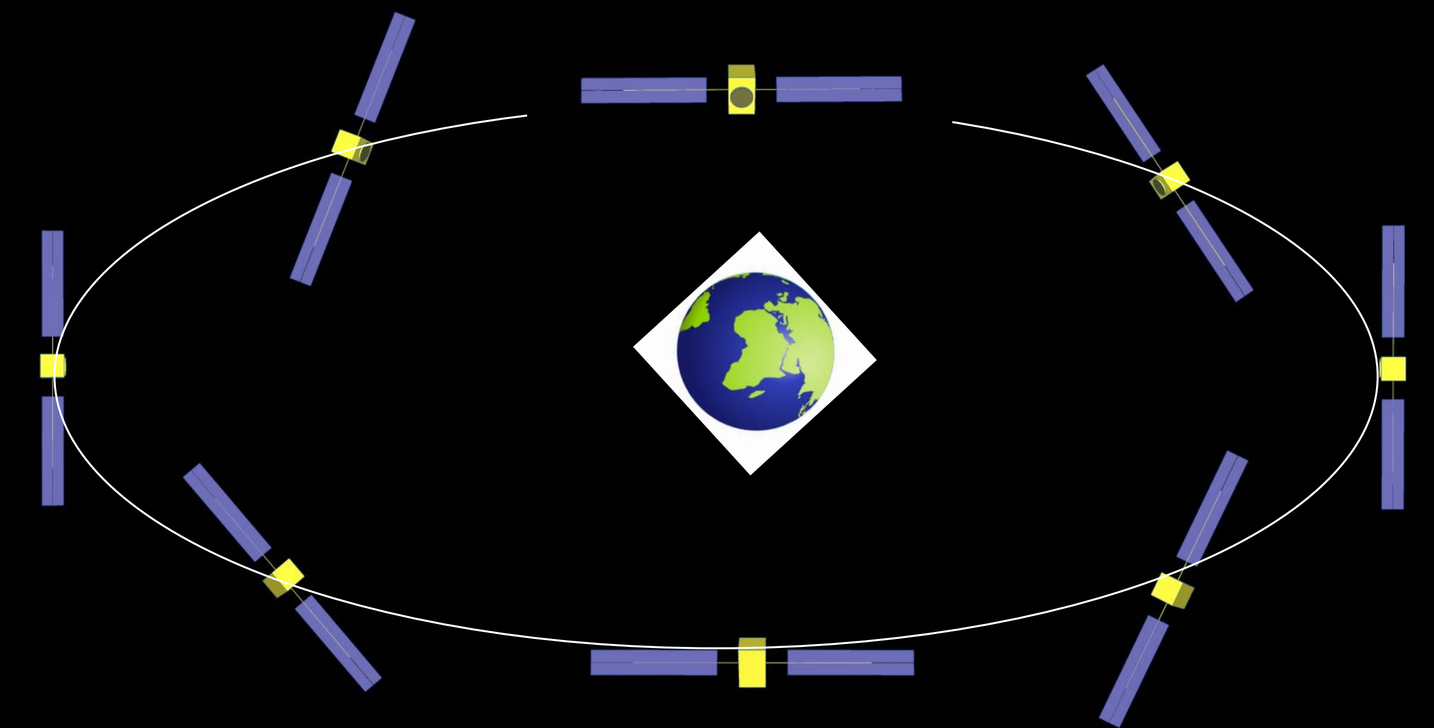
- ECOM: Empirical CODE Orbit Model (Beutler et al., 1994)
- Used in its reduced form (Springer et al. 1999) with 5 parameters

$$D(u) = D_0$$
$$Y(u) = Y_0$$
$$B(u) = B_0 + B_c \cos u + B_s \sin u$$

D: direction Satellite – Sun
Y: direction of solar panels axes
B: complete the orthognal system
u: argument of latitude

SRP modelling: the new ECOM

Satellite cross-section as seen from the Sun (Beta ≈ 30°) during one orbital revolution:



SRP modelling: the new ECOM

- The solar panels point to the Sun and causing only a constant perturbation in D-direction
- But the cross section of the satellite body as seen by the Sun varies
- New ECOM (Arnold et al., 2015)

$$D(u) = D_0 + D_{2c}\cos(2\Delta u) + D_{2s}\sin(2\Delta u) + D_{4c}\cos(4\Delta u) + D_{4s}\sin(4\Delta u)$$
$$Y(u) = Y_0$$
$$B(u) = B_0 + B_c\cos(\Delta u) + B_s\sin(\Delta u)$$

$\Delta \mathrm{u} \doteq \mathrm{u} - u_s,\ with$

u_s: Sun's argument of latitude in orbital plane

SRP modelling: the new ECOM

- The greater the periodic signals the greater the deviation of the shape of the body from a sphere


GPS


GLONASS


Galileo


BeiDou


QZSS

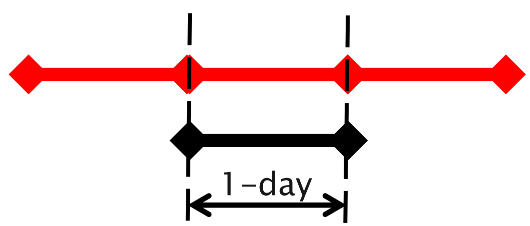
- Significant orbit improvement in particular for Galileo, GLONASS, QZSS

CODE MGEX clock solutions

- Four clock solutions are compared:

Solution ID	SRP ECOM	Orbital arc length [day]
O1	OLD	1
O3	OLD	3
N1	NEW	1
N3	NEW	3

- Orbital arc lengths:



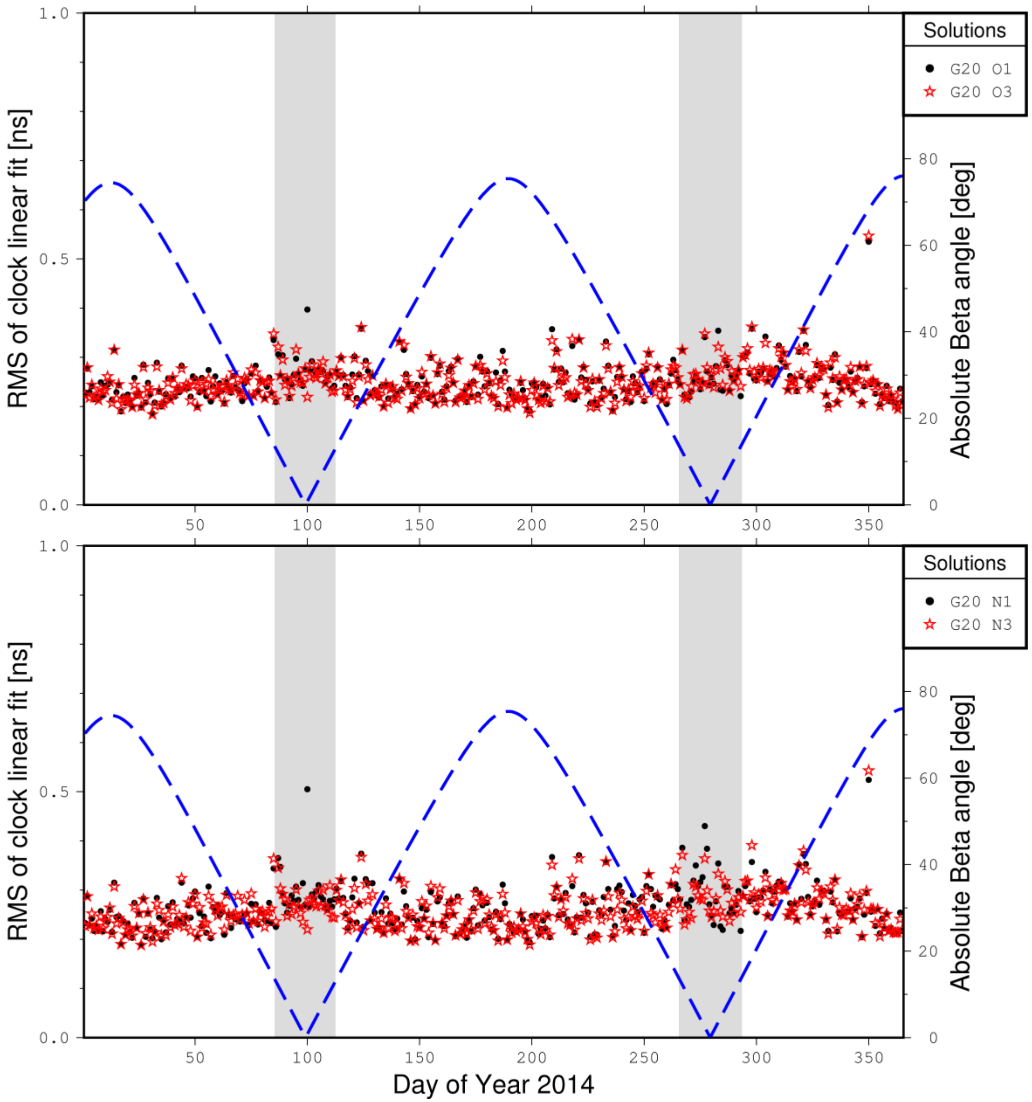
Generating long clock time series

- Alignment to IGS final timescale IGST (Ray & Senior, 2003)
  - GPS timescale (GPST) not stable enough on the short-term ($2x10^{-14}$ over 1-day intervals)
  - Stabilitiy of the IGST: $2x10^{-15}$ over 1-day intervals
- For non-GPS satellites, ISB alignment is also necessary:
  - In the parameter estimation, ISBs are estimated for each stations and each GNSS, applying a zero-mean condition
  - The alignement was performed by selecting a reference station over the period of interest

Satellite clocks performances

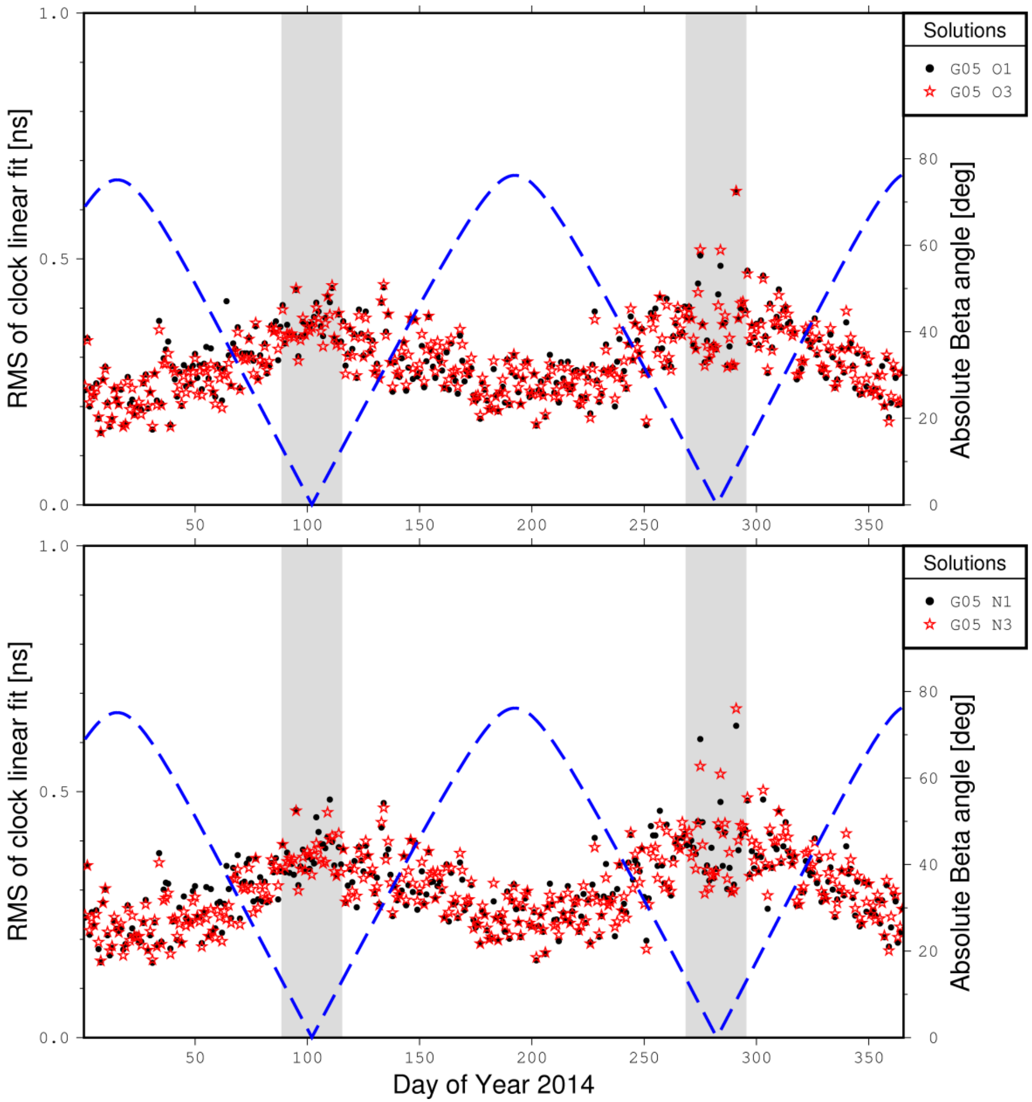
- Metric used: the RMS of linear clock fit over one day
- We look at the variations of the daily RMS over one year (2014)
- Summary table
- For representative satellites, presentation of:
  - Weekly time series
  - Modified Allan deviation plots from monthly time series
  - Power spectrum plots

GPS IIR Rb (G20)



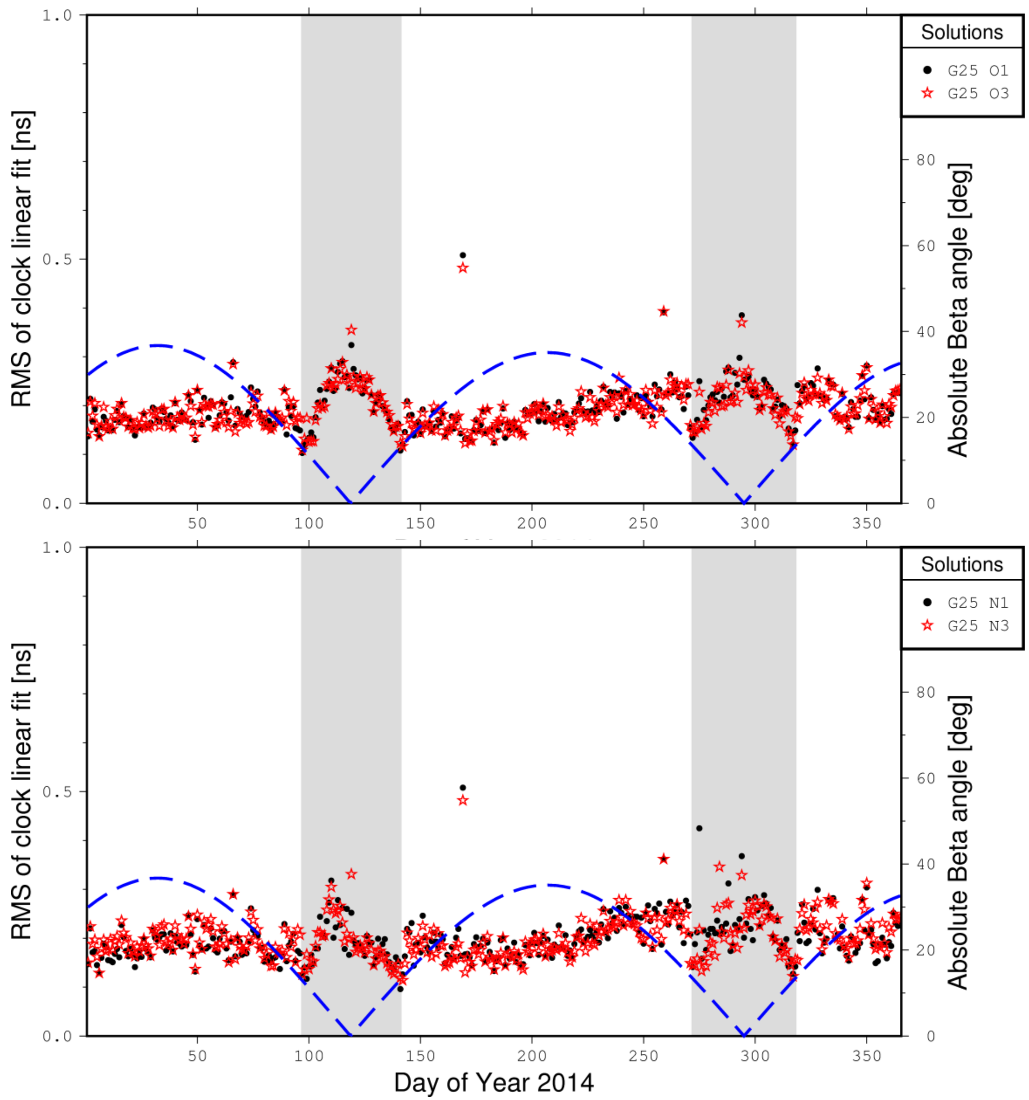
- Daily RMS in the region of 0.2–0.3 ns
- A slight dependence on the β angle can be observed
- No visible impact of either the orbital arc length nor the selected ECOM

GPS IIR-M Rb (G05)



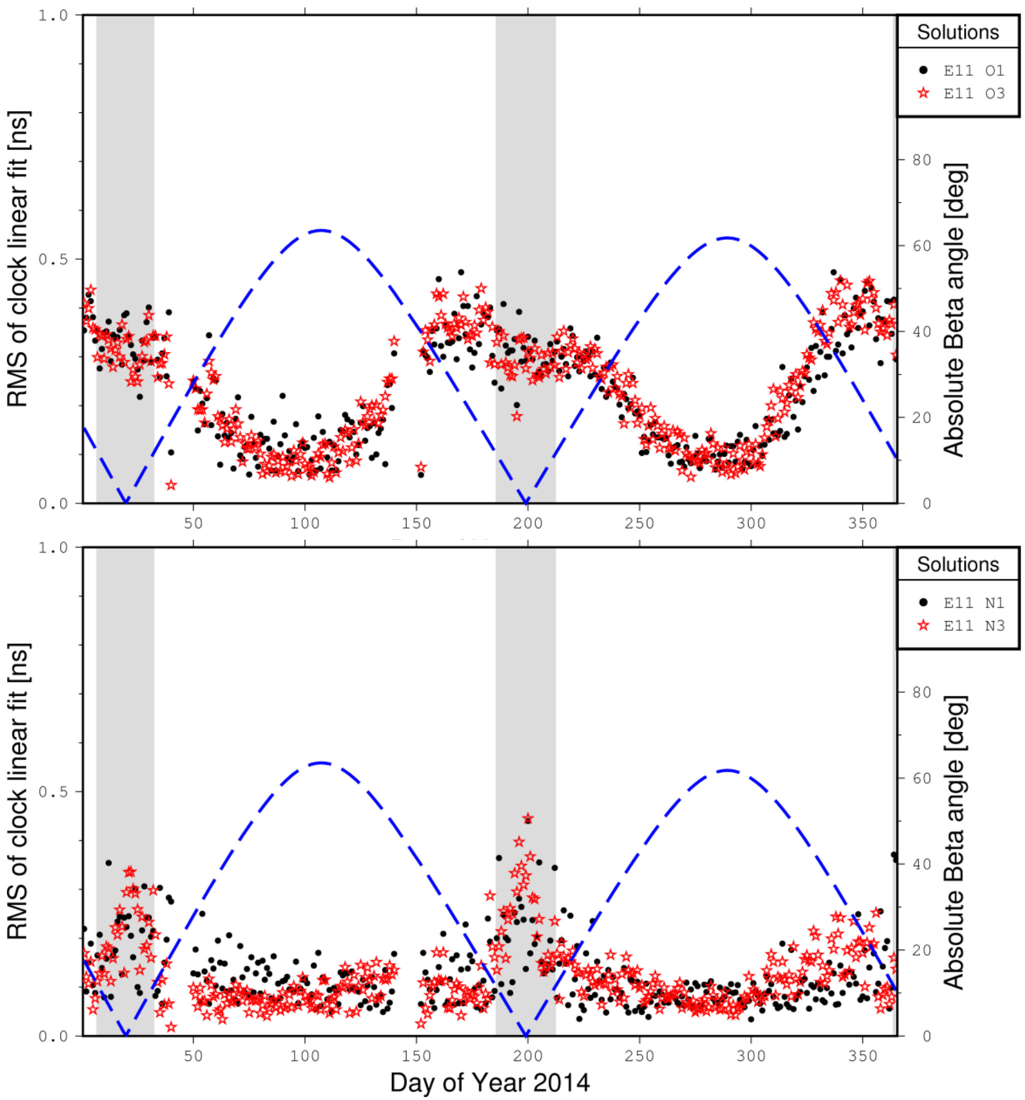
- Daily RMS in the region of 0.2–0.4 ns
- A more pronounced dependence on the β angle can be observed than for G20 IIR
- Highest degradation in shadow / noon-turns periods

GPS IIF Rb (G25)



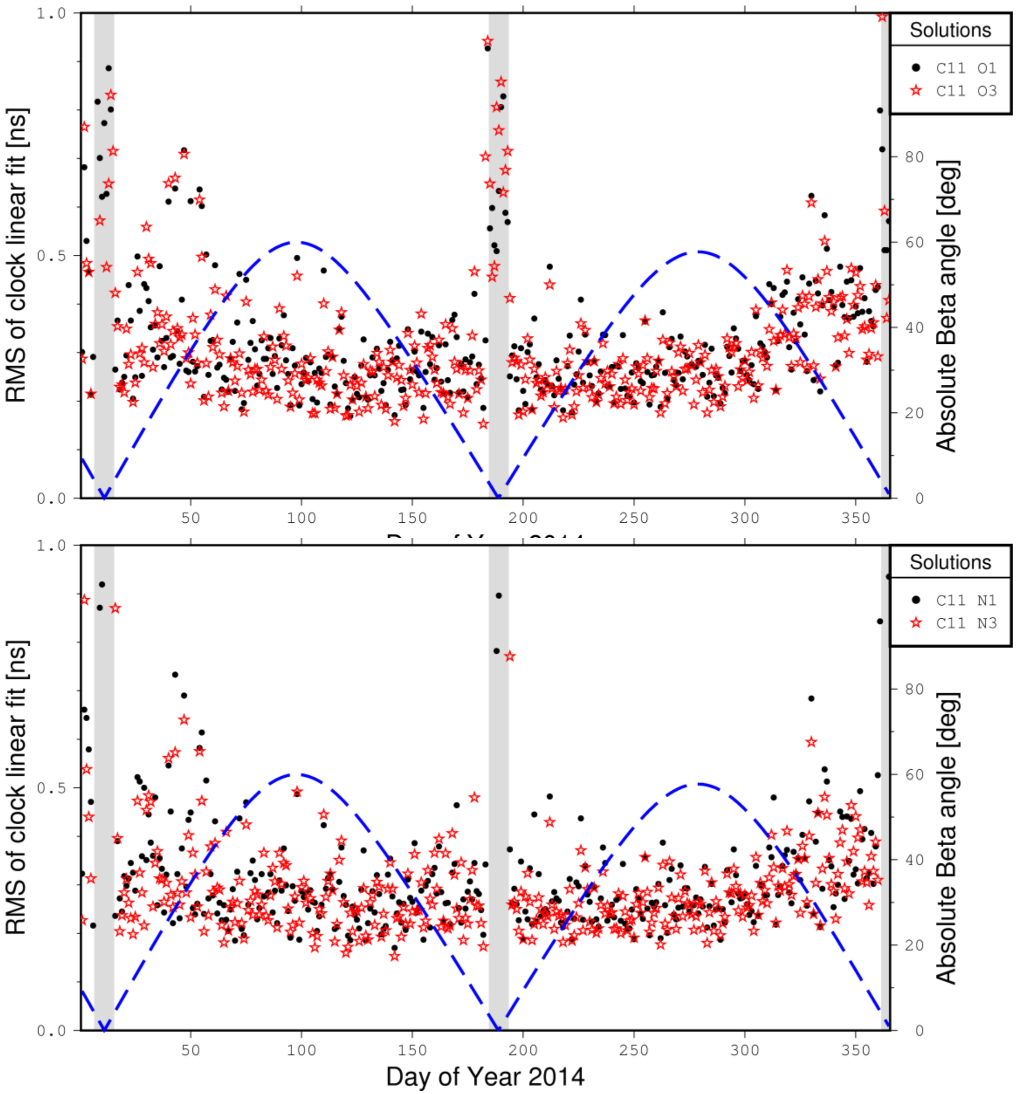
- RMS in the region of 0.1–0.2 ns
- Deficiencies in the attitude modelling in the shadow periods

Galileo PHM (E11)



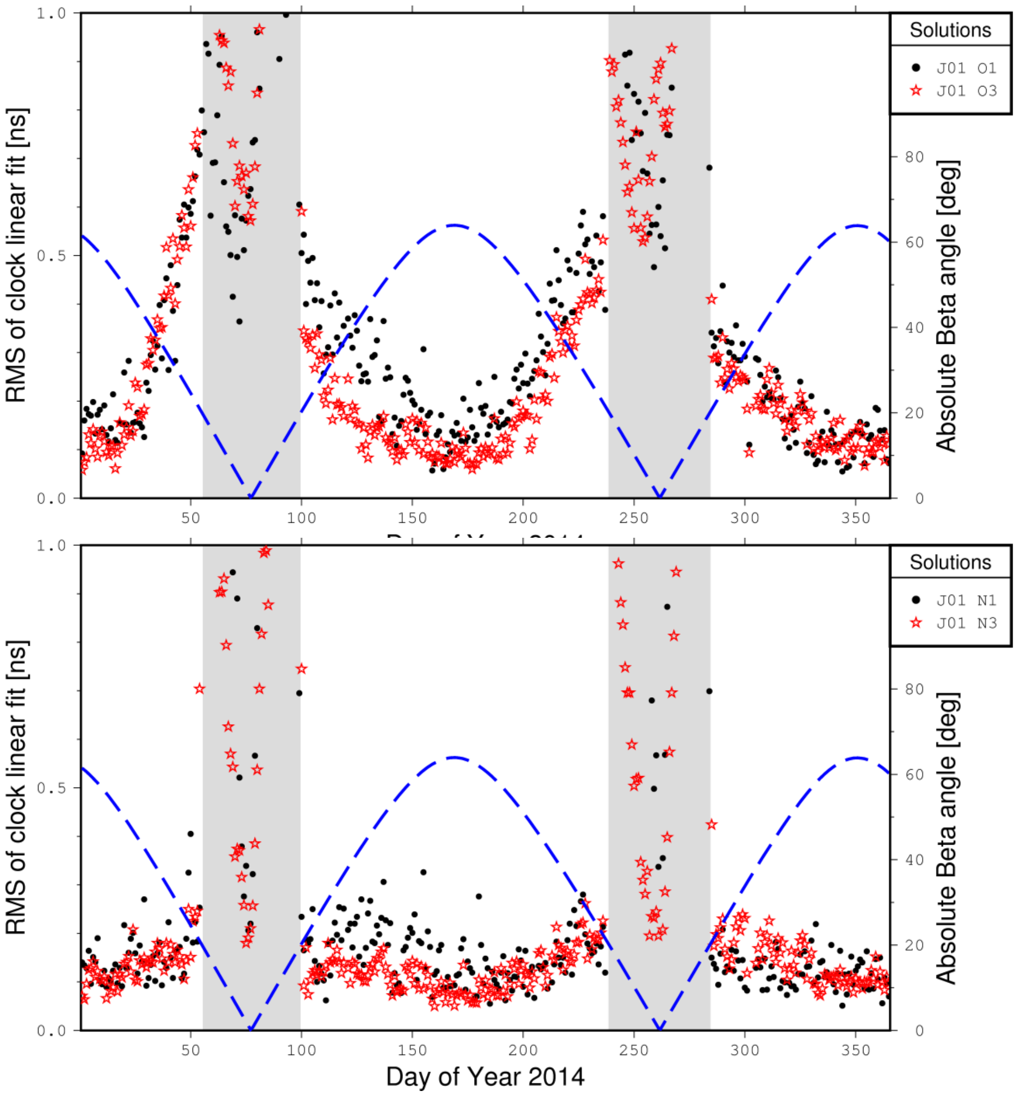
- Strong β dependency, with RMS between 0.1 and 0.5 ns
- The new ECOM significantly reduces the β dependency
- High RMS in shadow periods

BeiDou MEO Rb (C11)



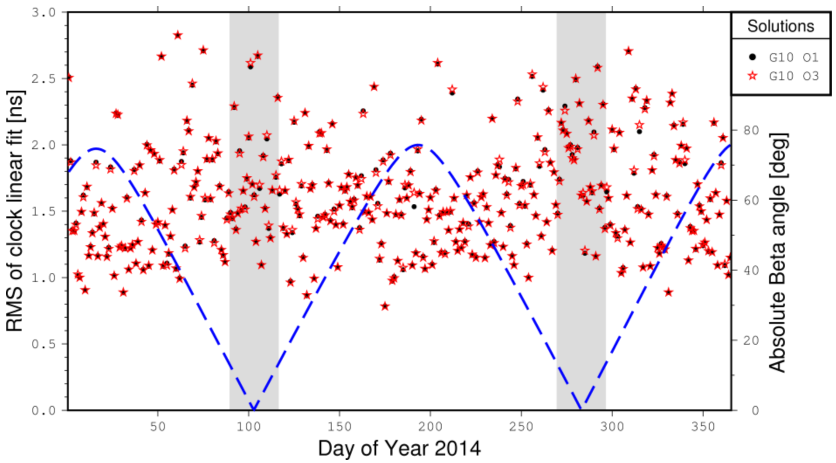
- Daily RMS mostly contained between 0.2 and 0.4 ns
- Strong degradation in a narrow band of ±4 deg (where new ECOM worsens the situation)
- Corresponds to the switch from yaw-steering mode to orbit 'normal' mode

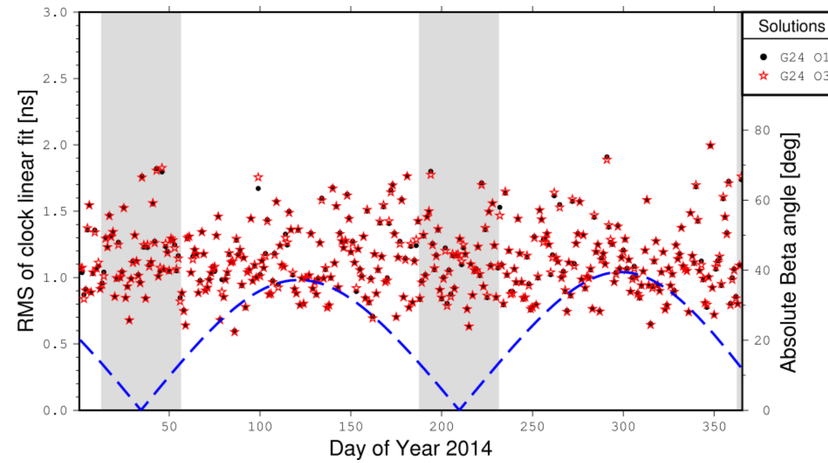
QZSS Rb (J01)

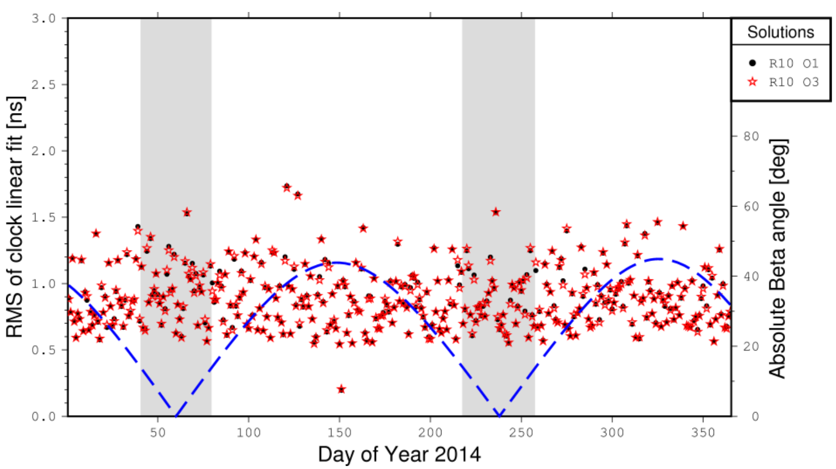


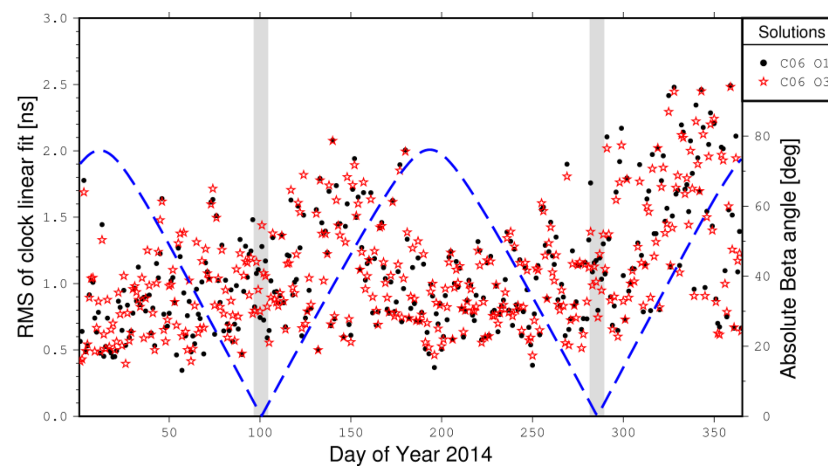
- Very pronouced β dependency
- Band of ±20 deg of high degradation, with a ‘V’ pattern
- Swtich to orbit ‘normal’ mode
- New ECOM clearly beneficial

GPS IIA Cs (G10), GPS IIF Cs (G24) GLONASS R10, BeiDou IGSO (C06)









Summary table on satellite clocks performances

GNSS / Subset	Solution -- mean (std) [ns]			
	O1	O3	N1	N3
GPS ALL	0.53 (0.67)	0.53 (0.67)	0.54 (0.66)	0.53 (0.66)
GPS IIF (Rb)	0.18 (0.08)	0.18 (0.08)	0.18 (0.09)	0.18 (0.09)
GLONASS	0.75 (0.44)	0.75 (0.44)	0.75 (0.44)	0.75 (0.44)
Galileo	0.24 (0.12)	0.24 (0.12)	0.13 (0.07)	0.13 (0.07)
BeiDou IGSO	0.61 (0.38)	0.60 (0.37)	0.63 (0.38)	0.61 (0.38)
BeiDou MEO	0.34 (0.24)	0.32 (0.26)	0.36 (0.27)	0.33 (0.28)
QZSS	0.26 (0.15)	0.24 (0.38)	0.17 (0.27)	0.17 (0.38)

- Old ECOM:
  - Overall consistent quality for the 1-day and 3-day solutions
  - Best (sub-)GNSS: **GPS IIF**
  - Second best GNSS: **Galileo**

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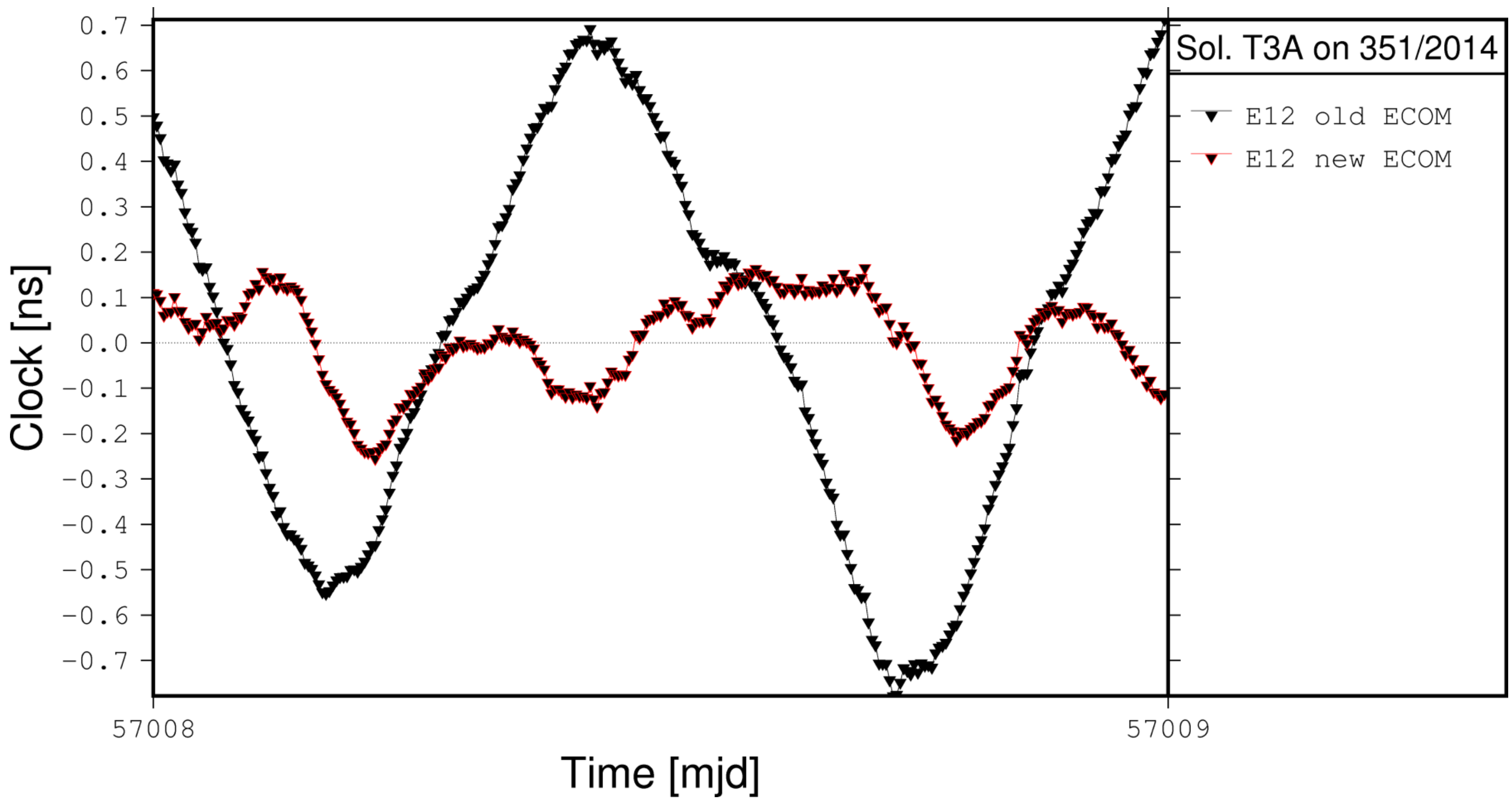
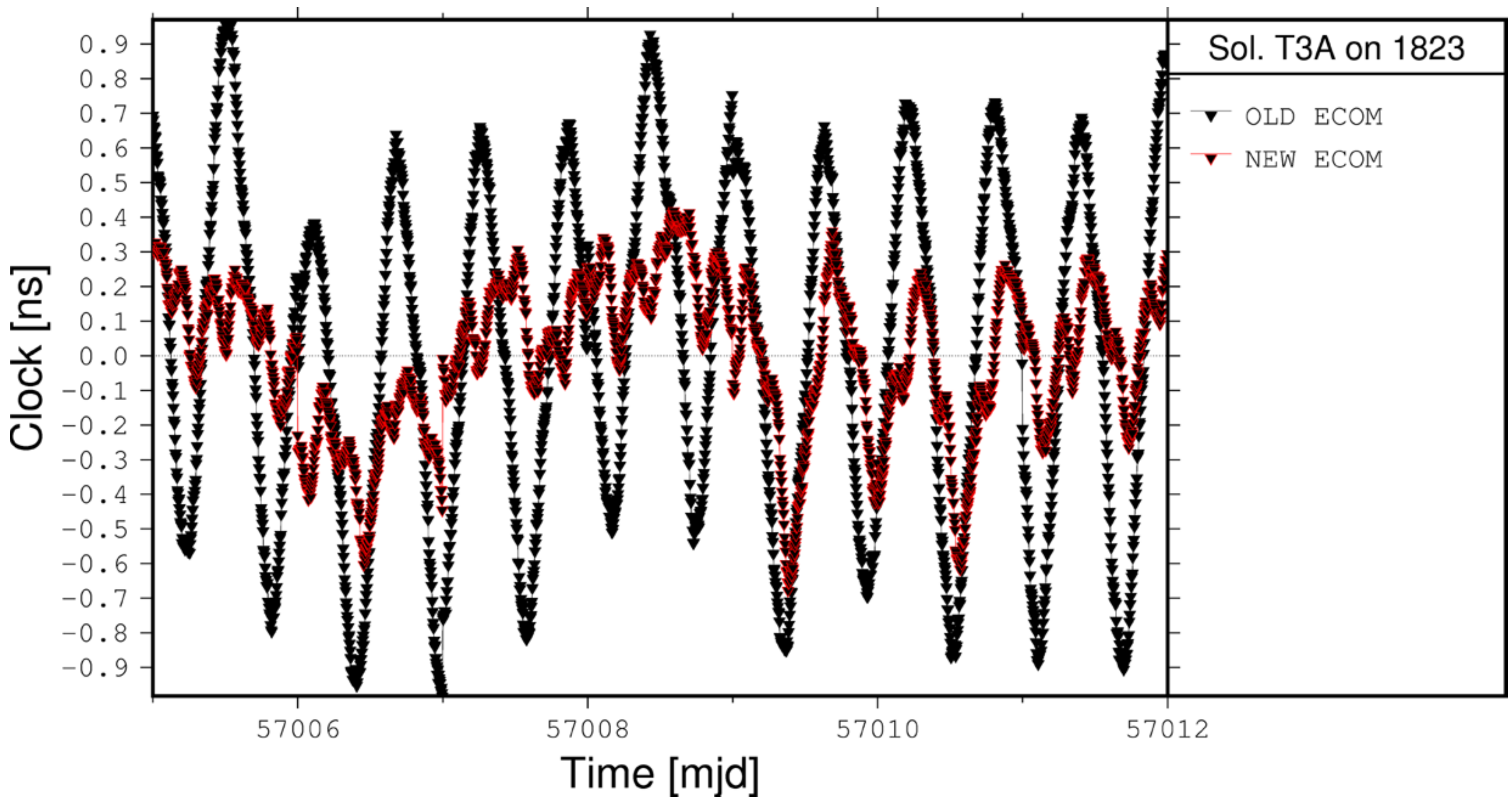
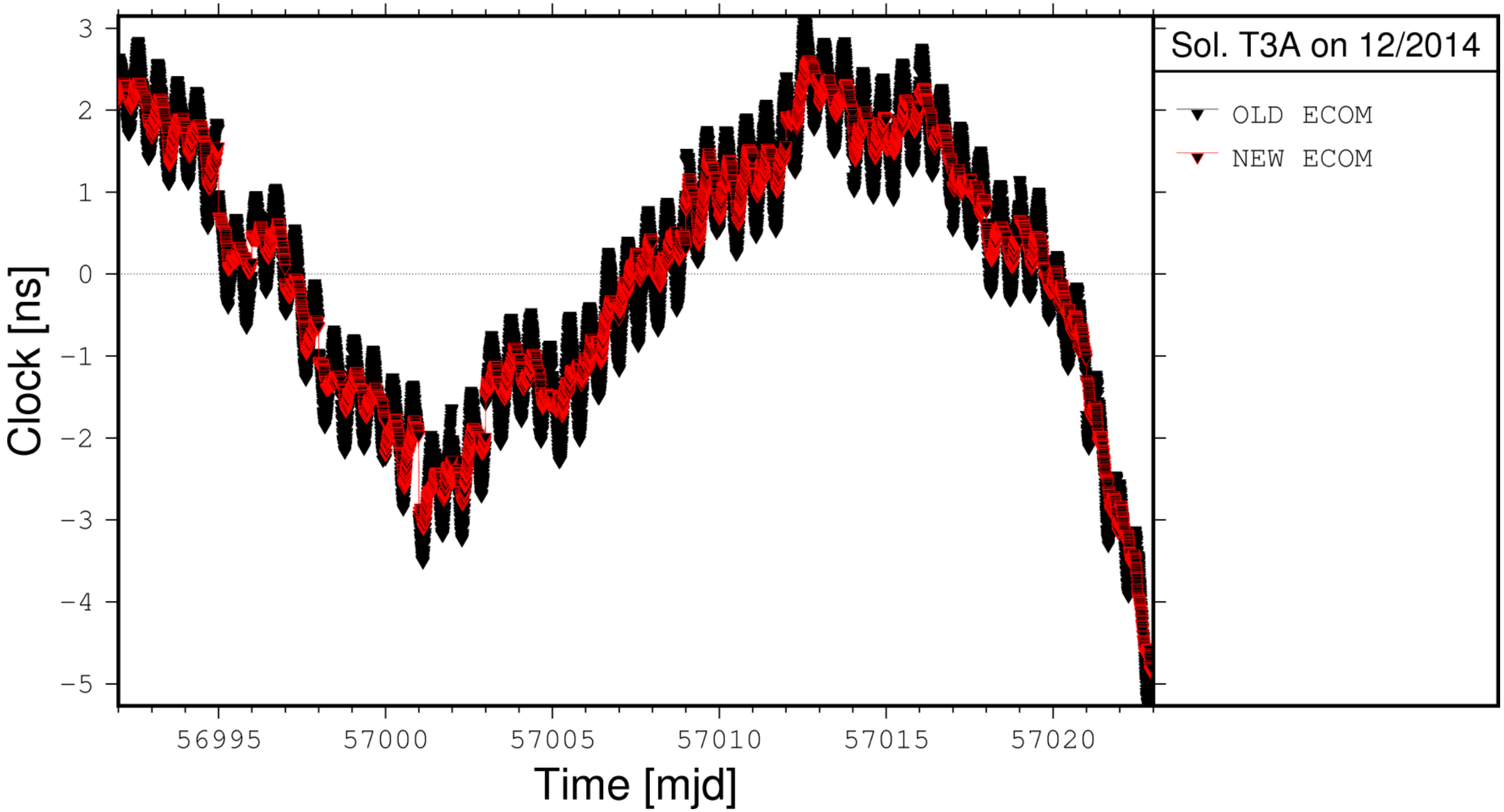
Impact of new ECOM
E12 daily clock time series



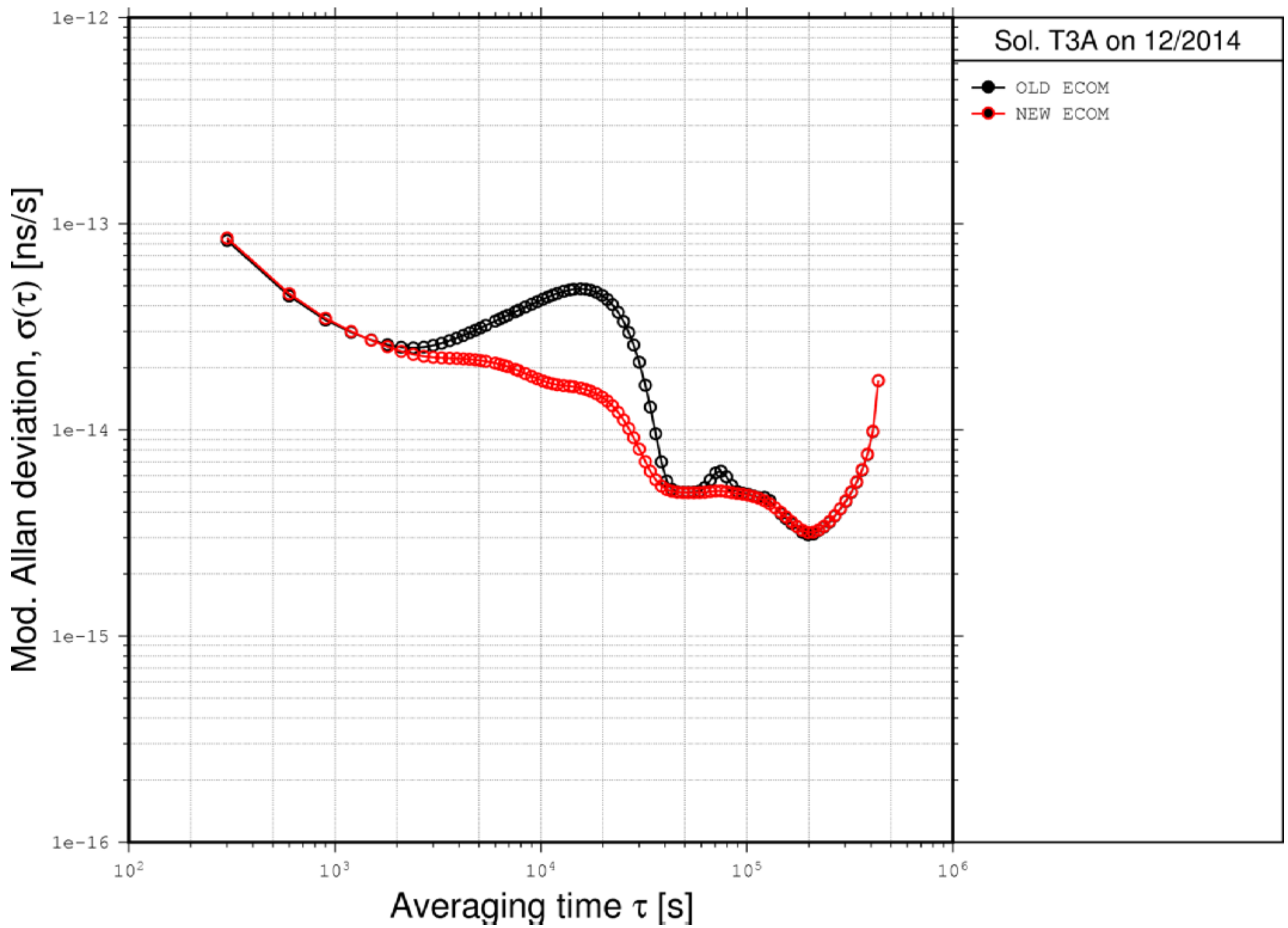
Impact of new ECOM
E12 weekly clock time series



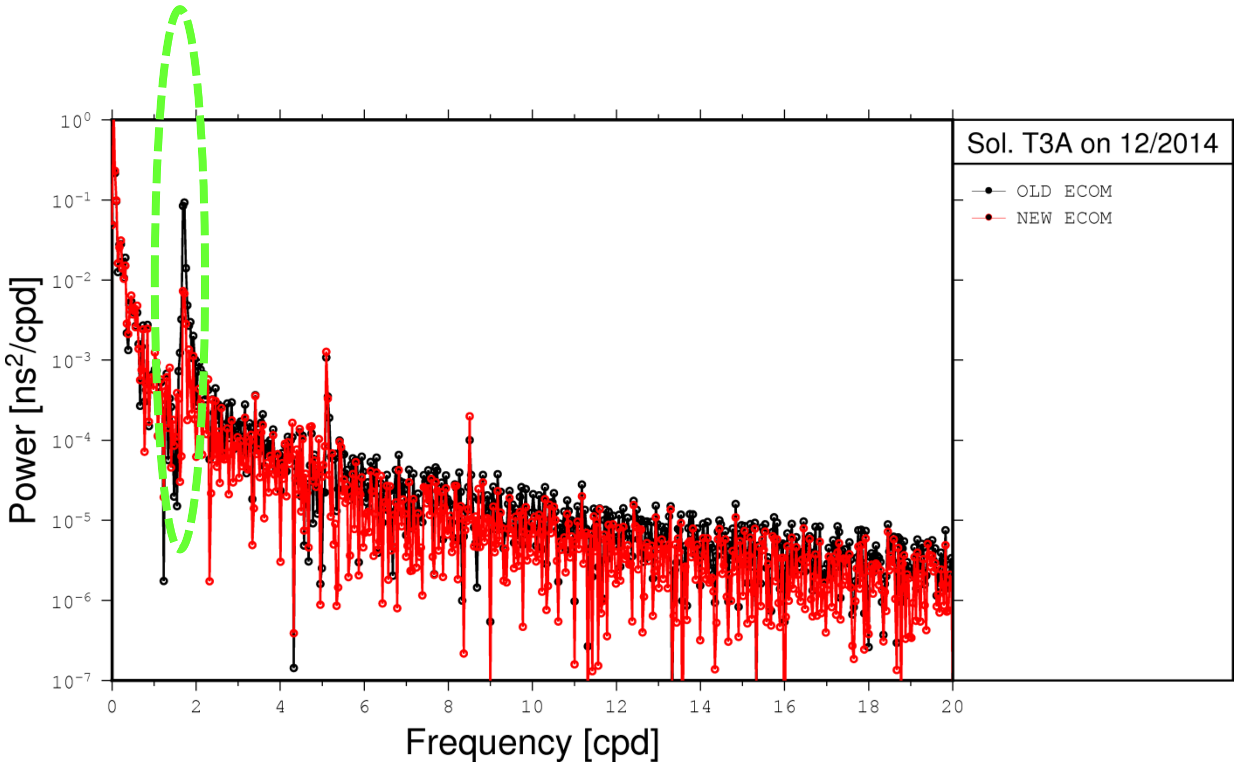
Impact of new ECOM
E12 monthly clock time series (December)



Impact of new ECOM
E12 Modified Allan Deviation

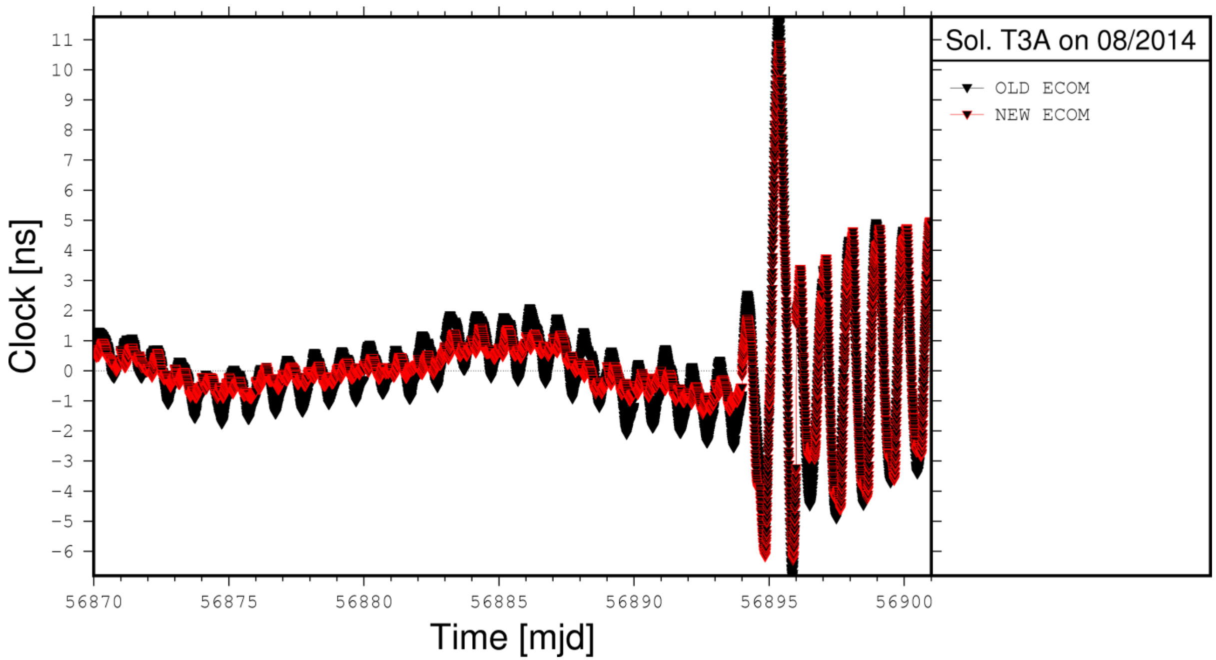


Impact of new ECOM
E12 power spectrum (from monthly TS)



- Overall reduced noise
- Main component at ~1.7 cyp (~14 hours/1 rev) clearly reduced with the new ECOM

Impact of new ECOM
J01 monthly clock time series



- QZSS J01 clock behavior when entering β band of ±20 deg

Conclusions & outlook

- The new ECOM has a significant positive impact in clock estimation for the Galileo and QZSS satellites
- Overall the 1-day and 3-day solutions perform similarly
- In a general sense, the attitude modelling in shadow periods shall be reviewed for all systems

Thank you for your attention!